

Passively Controlled Semi-Closed/Closed Rebreather

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LONG-TERM GOAL

The long-term goal of this research is to develop a versatile, passively-controlled semi-closed rebreather for deep diving applications that can be switched to closed-circuit mode during shallow water missions (depths less than 25 feet). Such a design is desired to safely satisfy the full range of Naval Special Warfare missions without the complexity and cost of electronically-controlled closed circuit rebreathers.

OBJECTIVES

The objectives of this effort were to optimize the design of respiratory-coupled circuit designs (using variable volume exhaust injection systems) using analytical predictive models, and verify from unmanned testing that safe alternatives to traditional semi-closed circuit designs are feasible. In so doing, we demonstrated that respiratory-coupled rebreather designs will provide divers with stable, and predictable circuit oxygen levels across their full range of activity levels.

APPROACH

Methods for predicting circuit oxygen partial pressures in traditional semi-closed circuit rebreathers have verified wide variations in these circuit oxygen levels over the full range of diver activity (Clarke *et al*, 1996; Nuckols *et al*, 1998; Nuckols *et al*, 1999). Limited experimental test results from the Navy Experimental Diving Unit (NEDU) have partially confirmed these theoretical predictions. These predictive methods were applied to an alternative semi-closed circuit design that couples gas injection with the diver's activity level (Nuckols *et al*, 1999). This analysis confirmed that this respiratory-coupled circuit concept gives much tighter control of circuit oxygen levels over the full range of diver metabolic requirements. Our first task was to validate these theoretical methods by comparing NEDU test data from evaluations of commercial rebreathers such as the U.S. Divers Oxy mix with current predictive models. We then used these validated predictive models to identify optimized design parameters, such as the ratio of the volume of compliant bellows to exhaust volume (EVR) and

makeup gas mixture, to best meet the operational requirements for Naval Special Warfare (NSW) missions.

Findings from these evaluations were used to specify the design of prototype semi-closed circuit rebreathers to passively inject fresh make-up gas on demand. Unmanned testing of these prototypes will be conducted in FY01 to verify the utility of analytical models in rebreather design, and prove the feasibility of maintaining uniform circuit oxygen levels across the full range of diver activity in NSW missions.

WORK COMPLETED

Validation of analytical models for semi-closed circuit rebreather design has been verified using archived NEDU test reports and recent unmanned testing of commercial rebreathers as described below. Applications of these models have been made to specify optimized design requirements for semi-closed rebreathers to meet specific NSW mission profiles.

RESULTS

Figures 1 and 2 compare the predicted circuit oxygen levels in traditional semi-closed rebreathers using constant mass injection (CMI) systems with those predicted for alternative respiratory-coupled, variable volume exhaust (VVE) injection systems. From a circuit oxygen level perspective it is apparent that VVE injection systems can potentially offer predictable, and uniform performance over the full range of diver activity levels. This behavior is most attractive for diver safety and mission versatility.

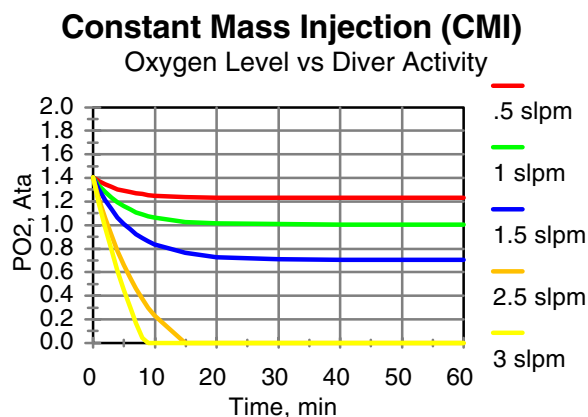


Figure 1: Circuit oxygen levels vs time delivered to a diver at a depth of 60 FSW when using a CMI semi-closed rebreather at oxygen consumption levels ranging from 0.5 - 3.0 slpm. A 50% oxygen mix is injected at 4.5 slpm into a circuit volume of 6 liters. (Circuit oxygen levels predicted using model described in Nuckols et al, 1998).

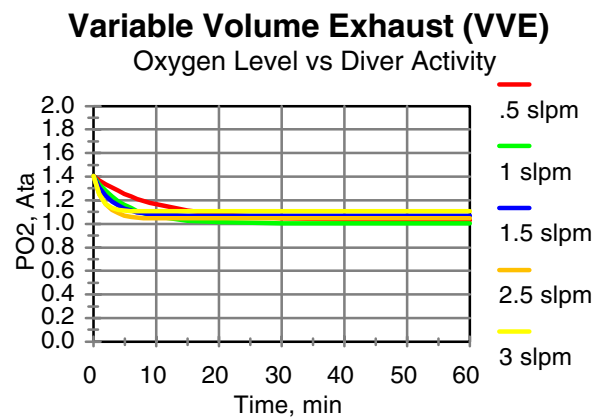


Figure 2: Circuit oxygen levels vs time delivered to a diver at a depth of 60 FSW when using a VVE semi-closed rebreather at oxygen consumption levels ranging from 0.5 - 3.0 slpm. A 50% oxygen mix is injected with an EVR of 6.25% into a circuit volume of 6 liters. (Circuit oxygen levels predicted using model described in Nuckols et al, 1999).

During June 2000 the U.S. Divers Oxy mix 3C, a semi-closed rebreather that utilizes a VVE injection system, was tested at three different depths and three different simulated diver activity levels at the Navy Experimental Dive Unit in Panama City, FL to verify the circuit oxygen levels predicted above. Figure 3 compares the stabilized oxygen levels recorded during these unmanned tests with model predictions for two different exhaust volume ratios (EVR). Observe that the model predictions most closely match the test data with an EVR of 7.5% as opposed to the EVR that was reported by U.S. Divers (10.9%), or the EVR that was statically measured prior to testing (10%). The model was shown to be very effective in predicting circuit oxygen levels over a wide range of depths and activity levels when the proper EVR is utilized. Once this ratio had been accurately determined, the model was used effectively to predict the operational range of any rebreather using a variable volume exhaust mechanism for gas supply mixtures containing varying percentages of oxygen, as shown in Figure 4.

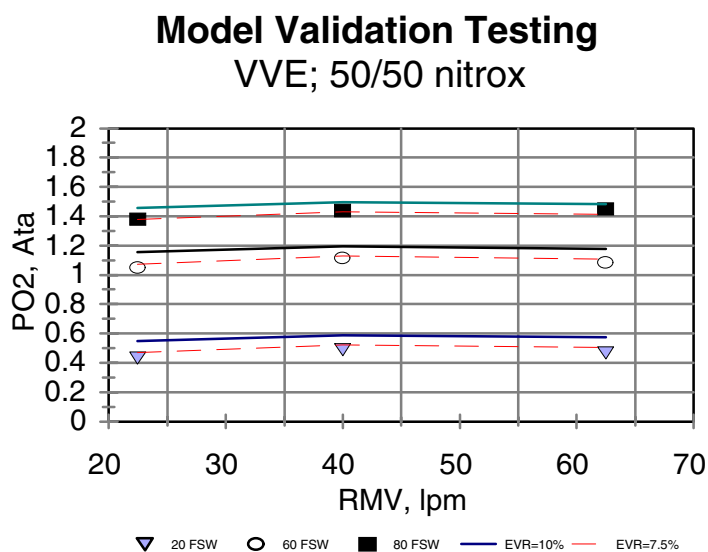
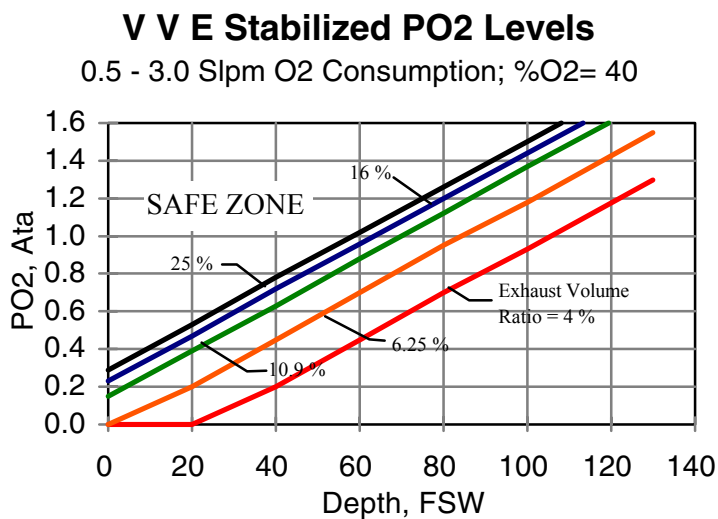


Figure 3: Comparison of recorded circuit oxygen levels in the Oxy mix rebreather with those predicted with EVRs of 7.5% and 10%.

Figure 4: Predicted safe operational ranges for VVE rebreathers having different exhaust volume ratios when using a gas supply containing 40% oxygen.



Based on the testing with the Oxymix, we obtained a prototype rebreather containing a bellows EVR of approximately 7.5% from Halcyon, Inc. Unmanned testing was conducted on this prototype at NEDU during the week of 24 July. Three test depths (20, 60, and 100 FSW) and three RMV levels (22.5, 40, and 62.5 lpm) were investigated during these model validation tests. Figure 5 compares these test data with model predictions for an exhaust volume ratio of 7.5%.

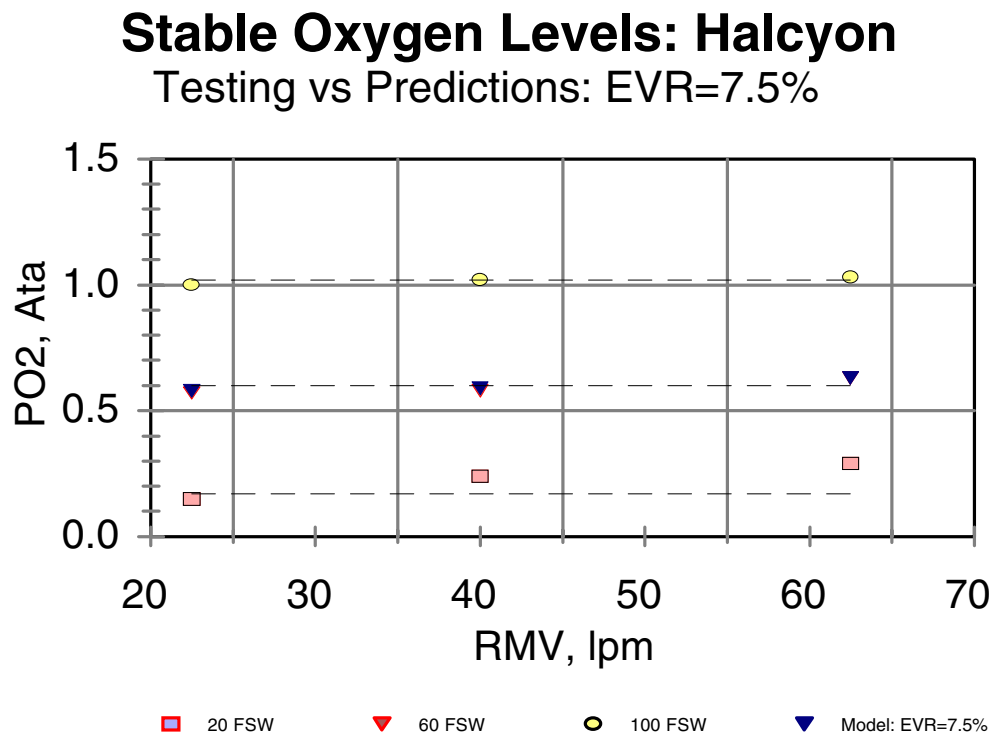


Figure 5: Comparison of recorded circuit oxygen levels in the Halcyon prototype rebreather with those predicted with the model using an EVR of 7.5%.

Modeling an EVR of 7.5% showed good agreement with the test data at depths of 60 feet and 100 feet across the full range of simulated diver activity levels. Although poorer agreement was observed at depths of 20 feet, the test data still highlights the advantages of using a VVE type mechanism for gas injection. These tests confirmed that good agreement between modeling and rebreather performance can be seen when a consistent EVR can be measured.

IMPACT/APPLICATION

One anticipated application of this technology would be Naval Special Warfare personnel deployed from the Advanced SEAL Delivery System (ASDS). The desired lockout depth from the ASDS will probably be deeper than can be supported with closed-circuit, pure oxygen rebreathers such as the LAR V. Although the MK 16 mixed-gas closed-circuit rebreather could support the depths required for ASDS diving operations, its size and complexity would make its use unpopular. A passively-controlled semi-closed rebreather, which can be switched to closed-circuit mode, could satisfy the full

range of the ASDS mission without the complexity and cost of the MK 16. The simple respiration-coupled gas supply feature of this design would give the diver a predictable oxygen level in his circuit which would minimize the determination of oxygen dosage levels and any decompression obligations.

TRANSITIONS

Our ongoing efforts in the modeling of rebreathers have resulted in new analysis capabilities for engineers at the Coastal Systems Station (CSS). These models were recently utilized by CSS to evaluate commercial rebreathers for PMS 325 (Contact: Wes Hughson). Additionally, we are maintaining a close liaison with NEDU and the NSW community to ease the introduction of this type of respiratory-coupled rebreather into service. During the past year we briefed this project with PMS 325 (contact: LT David Hoagland), NEDU (contact: CAPT Marie Knafelc), the VSW/SZ Diver Technology Workshop held in Panama City, FL during 11-13 July, and the Fleet Diving Issues meeting in Panama City, FL during 9 August. Upon satisfactory completion of this effort the results will be widely disseminated in an effort to gain commercial acceptance of this optimized rebreather system.

RELATED PROJECTS

This research effort furthers fundamental knowledge in diver life support equipment design. The validated models have already been beneficial in characterizing the performances of commercial rebreathers for Naval Special Warfare applications. Additionally, they could be used to help characterize life support equipment now being used in very shallow water, mine-countermeasure (VSW-MCM) missions.

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